EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Life, Earth and Environmental Sciences (LESC)

Standing Committee for Physical and Engineering Sciences (PESC)

ESF Exploratory Workshop on

Biosignatures On Exoplanets; The Identity Of Life

Mulhouse (France), 22-25 June 2009

SCIENTIFIC REPORT

Executive Summary

In the last decade, using a variety of different detection techniques, more than 400 planets orbiting other stars, so called extra solar planets (or exoplanets) have been reported[1]. Most of these are ‘gas giants’ believed to resemble Jupiter in our own Solar but this is largely an effect of a sampling bias - since larger planets were obviously easier to detect than smaller, rocky, Earth-like planets. However, recently (2008) with improving detection techniques, three Super-Earth’s (masses 4-9 those of Earth) were reported by Michel Mayor in system HD40307 and this year the smallest exoplanet (with a mass estimated to be only 1.9 times that of Earth) was reported in the Gleise System, whilst October 19, 2009 saw the most planets ever announced in a single day (30). Thus we can confidently expect several hundred exoplanets to be detected in the coming decade, many of which may be ‘Earth-like’ and some of these will be sited in the so-called ‘habitable zone’ – that region where an Earth-like planet can maintain liquid water on its surface and thus have the possibility of sustaining Earth-like life.

Thus it is now necessary to look forward and consider how we might search for characteristic (spectral) signatures that will identify the presence of life on such exoplanets. It should be stressed that we are not looking for ‘technologically advanced civilizations’ but rather we plan to look for the physical and chemical signs of fundamental life processes; so called ‘biosignatures’. This is timely since the next generation of telescopes (e.g. NASA's Terrestrial Planet Finder (TPF) and ESA’s Darwin missions) are now at the design stage, telescopes which will provide the first opportunity for detection of such ‘biosignatures’ but in order to optimize such designs it is necessary to first identify such biosignatures and how they may be distinguished from the abiotic (natural) background.

Much information may be gained by using our own Earth as an exemplar case. We can use previously launched space missions to look back at Earth and identify biosignatures of life on Earth from such observational data. However we should not be ‘Earth Centric’ since the different physical and chemical conditions on exoplanets must be expected to lead to life evolving in different ways. By developing simple models (e.g. of photosynthesis under different optical spectra of different types of stars) we can make some predictions as to how flora may adapt to different exoplanetary environments.

This ESF Exploratory workshop was aimed at bringing together researchers from a variety of disparate fields to identify the most promising candidates for biosignatures and discuss methods and technologies for identifying them in the atmosphere and surface of exoplanets.

The workshop concluded that a priority for the research community seeking to develop a methodology for detection of biological processes in any planetary atmosphere is the construction of models of simulated planetary atmospheres whose parameters can be varied to determine the effect of different scenarios from life rich to barren planets. Such models must be able to predict the temporal evolution of the atmosphere as life in

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[1] For a constant update see the **The Extrasolar Planets Encyclopaedia** on http://exoplanet.eu/

its varied forms develops (e.g. it should be able to follow the growth of oxygen/ozone as photosynthesis develops). Several models already exist but to date have not been stringently compared with one another and may (do) use different datasets and assumptions to describe the physical and chemical processes whilst the description of the biology is limited, in part due to lack of direct input from the biology community (for example there is no agreed rate for averaged CO_2 absorption/oxygen emission per unit mass of biota). A meeting bringing together researchers to identify a common protocol for defining the parameters for developing an example exoplanet atmosphere which includes biological processes is needed. Such parameters can then be run in different models and cross correlated with one another. However such models may still have systematic effects with errors in the basic assumptions, accordingly as it is necessary to benchmark these models with experimental simulations. Indeed our knowledge of physical and chemical processes in both the Martian and Titan atmosphere has been greatly altered by an iterative comparison of planetary atmosphere models and laboratory planetary atmosphere simulations.

The ESF workshop therefore proposed that there is a need to develop an experimental simulation of exoplanet atmospheres that may be directly compared with the models. A follow up meeting is proposed (for January 2010) the details of which are presented below. Such a workshop may act as the catalyst for developing a larger scale interdisciplinary European research programme to develop the field of exoplanetary studies. Future research may also be coordinated through a recently awarded COST Action (CM0805) The Chemical Cosmos, which included a working group on 'Planetary Atmopsheres' allowing staff exchanges and further workshops to be arranged in 2010-13. Access to experimental facilities to develop laboratory simulations of exoplanetary atmospheres and surfaces as well as terrestrial field sites that may mimic 'exoplanetary' conditions may also be provided by the Europlanet Research infrastructure (2009-12).

Scientific content of the workshop

The meeting was organised into five scientific sessions;
Session 1; Exoplanets- defining the habitable zone
Session 2; Biosignatures, the identity of life
Session 3; Exoplanetary Atmospheres
Session 4; Looking for Vegetation
Session 5; Instrumentation

Each Session comprised several talks each followed by a discussion session. The meeting was concluded with a session dedicated to a forward look and a discussion of how the field may be developed.

The Habitable zone

In the first session the definition of a 'habitable zone' was discussed. It was clear that this remains a somewhat vague term and should not be confused with 'planetary habitability' While the latter concentrates upon the physical and chemical conditions on the exoplanet required to sustain life[2] the habitable zone defines the stellar conditions required to maintain/develop life. For life to have evolved and be sustained it is believed that the planet on which it is based must be within a region of its solar system where water is in liquid form since this is necessary for both maintaining the structure of basic celluar components (such as membranes) and providing a solvent within which basic biochemistry may occur. Identifying the presence of exoplanets within such 'habitable zones' is therefore a prerequiste for the search for life in exoplanetary systems. However in order to characterise the 'habitable zone' in any solar system models of the complete exoplanetary systems must be made since planets may 'migrate' through young solar systems. Furthermore it is possible that any solar system supporting life may need one or more large planets to protect habitable planets from asteroid impacts (as Jupiter does Earth). The meeting reviewed the development of computer models that are capable of simulating discovered exoplanetary systems such that we can determine which provide the best candidates for supporting Earth like planets in a habitable zone and thus refine the search programme of next generation of planetary search missions (e.g. Kepler, New Worlds Mission, Darwin, Space Interferometry Mission, Terrestrial Planet Finder and PEGASE).

Determining Biomarkers

Having detected exoplanets in designated habitable zones the search may begin for evidence of life itself. Not intelligent life but fauna and bacterial which influence the atmospheric composition and surface albedo. To distinguish biological from abiotic processes it is necessary to define distinct 'biomarkers' whose (spectral) signatures are clear. The preferred wavelength ranges for space base telescopes lies between 7 to 25 microns in the mid-IR, and 0.5 to about 1.1 microns in the visible to near-IR. Suggested biomarkers with spectral signatures in these regions are O_2 and its photolytic product O_3 (large concentrations of which are believed to be evidence for photosynthesis); liquid

[2] Note in this meeting life was defined as carbon based with a familiarty to that on Earth.

H_2O - which whilst not a bioindicator is considered essential to life; CO_2 - significant concentrations of which indicates an atmosphere and oxidation state typical of a terrestrial planet and CH_4 which if present in significant concentrations is suggestive of a biological source. However all these compounds can have abiotic sources for example ozone has recently been found on several Saturnian moons, being induced by magnetospheric interaction with the lunar surface whilst CH_4 can also arise from a crust and upper mantle more reduced than that of Earth.

The meeting reviewed such possible biosignatures and their possible abiotic sources while discussing other gaseous emissions which provide a more unique biomarker. One possibility is to search for methanethiol (CH_3SH), which is produced during the decay of biological material. This compound, also called methyl mercaptan, is created through the degradation of the amino acid methionine. Since all life we know uses amino acids there is every reason to think methionine was used by early life and may be a common ingredient of life.

Exoplanetary atmospheres

In seeking to detect life on an exoplanet we may either seek to detect specific biomarkers as gases in the planetary atmosphere or perhaps seek to detect life by viewing the reflection spectrum/albedo of the planetary surface. On February 21, 2007, NASA and the Journal Nature released news that HD 209458 b and HD 189733 b were the first two extrasolar planets to have their spectra directly observed and both methane and water had been identified in atmosphere of exoplanet HD 189733 b. Although the physical conditions on HD 189733 b are believed to be too harsh to support life these observations demonstrated that it is possible to detect key organic molecules on an extrasolar planet. This session reviewed these results and crucially discussed how life may create a finger print in any planetary atmosphere. The atmosphere of the early Earth (pre-photosynthesis) was reviewed as a example. Questions asked and discussed included; How much (by mass) of biota would be necessary to reveal a biosignature ? What would be the signature of non photosynthetic life ? How would the atmosphere of an exoplanet colonised by methanogens and/or acetogens develop. Are non-carbon based life forms (e.g. biogenic silica) viable ?

Looking for Vegetation

In this session the possibilty of observing vegetation on a remote planet was examined. This issue may be addressed by looking at Earth from Space. For example identifying spectral signatures in terrestrial surface albedo or Earthshine (the spatially integrated scattered light spectrum of Earth) to identify chlorophyll both in plants and photoplankton. Earth's deciduous plants have a sharp order-of-magnitude increase in leaf reflectance between approximately 700 and 750 nm wavelength, referred to as the "red edge". This strong reflectance of Earth's vegetation suggests that surface biosignatures with sharp spectral features might be detectable in the spectrum of scattered light from a spatially unresolved extrasolar terrestrial planet. However in exploring exoplanetary systems we must be aware that flora may develop new characteristics dependent upon the spectrum of their own Sun. Models may be developed that will provide a reference for photosynthetic pigments on planets around F2V stars may peak in absorbance in the blue, K2V in the red-orange, and M stars in the near-infrared, in bands at 0.93-1.1 μm, 1.1-1.4 μm, 1.5-1.8 μm, and 1.8-2.5 μm.

Instrumentation

In this final session the instrumentation capable of looking for, and identifying life, was reviewed with examples drawn from the study of extremophiles on Earth and the development of probes for exploration of Mars. The design and operation of experimental facilities to mimic planetary surfaces and atmospheres was also reviewed. Currently these are based on mimics of planetary bodies in the Solar System but the discussion questioned whether they could be developed to provide a test of exoplanetary models and simulate conditions for exploring detection biosignatures in exoplanetary atmospheres.

The meeting concluded with a detailed discussion reviewing the material presented in the scientific sessions and a methodology for advancing the field. The major conclusion of this discussion was that there was a major need to establish a mechanism for bringing researchers from disparate disciplines to develop a more coherent research programme aimed at both identifying biosignatures on exoplanets and developing methodologies for detecting them remotely (spectroscopically). Such a research programme will be critically based on the development of models of exoplanetary atmospheres and the need to develop an experimental simulation of exoplanet atmospheres that may be directly compared with such models. A follow up workshop to scope an exoplanetary atmospheric model was proposed and is planned for January 2010.

Assessment of the results, contribution to the future direction of the field, outcome

The ESF Exploratory workshop on identifying biomarkers in exoplanets provided the first opportunity for researchers from diverse research fields (observational astronomy, molecular science, molecular spectroscopy, planetary science and (paleo)climate studies) to meet in a targeted workshop environment to both review progress in the detection and observation of exoplanets and to discuss how the evidence for the existence of life may be derived from remote observation of exoplanets via the identification of molecular biomarkers in the atmospheres of such planets (or within the planetary albedo).

Several molecules have been suggested as potential biomarkers; water (required for cellular structure and stability); methane (prominent in bacterial respiration) and carbon dioxide and molecular oxygen (fingerprints of photosynthetic processes) - although, since molecular oxygen in not infrared active, detection of ozone (formed through UV photodissociation of O_2) has been suggested as a secondary monitor of a photosynthetic active planet. Using the Earth as our only known example of a life supporting habitat other volatile hydrocarbons generic of its flora were also suggested as biomarkers but are present in such low concentrations that it is unlikely that they could be detected even by the next generation of space telescopes. The workshop discussed the advantages and disadvantages of such ‘biomarkers’ and concluded that;

- For every suggested biomarker there are abiotic sources which may dominate over any biogenic process, e.g. ozone can be formed by irradiation of oxygen containing ices on the planetary surface. Hence in order to define whether a planet is supporting a biosphere a set of molecular species should be detected simultaneously.

- For any definitive conclusions of observations it will be necessary to build a atmospheric (climate) model of the planet including physical, chemical *and biological* processes. Such models should model how much biota is necessary for there to be detectable biosignature, for example the Earth is ‘life rich’ so temporal changes in photosynthetic signals can be detected directly but should the biota be limited to only part of the surface of an exoplanet the biosignature may be dominated by abiotic processes. Similarly if a planet is observed early in life’s evolution the biota may be small or may be different from that in its mature state e.g. in the early stages of the Earth life was methane based rather than oxygen (photosynthetic) based.

Accordingly the workshop concluded that a priority for the research community seeking to develop a methodology for detection of biological processes in any planetary atmosphere is the construction of models of simulated planetary atmospheres whose parameters can be varied to determine the effect of different scenarios from life rich to barren planets. Such models must be able to predict the temporal evolution of the atmosphere as life in its varied forms develops (e.g. it should be able to follow the growth of oxygen/ozone as photosynthesis develops). Several models already exist but to date have not been stringently compared with one another and may (do) use different datasets and assumptions to describe the physical and chemical processes whilst the description of the nascent biology in such models is limited, in part due to lack of direct input from the biology community - for example there is no agreed rate for averaged CO_2 absorption/oxygen emission per unit mass of biota. A meeting bringing together researchers to identify a common protocol for defining the parameters for developing an example exoplanet atmosphere which includes biological processes is therefore needed. Parameters can then be changed in different models and cross correlated with one another. However such models may still have systematic effects with errors in the basic assumptions, accordingly as it is necessary to benchmark the models with experimental simulations. Indeed our knowledge of physical and chemical processes in both the Martian and Titan atmosphere has been greatly altered by an iterative comparison of planetary atmosphere models and laboratory planetary atmosphere simulations. The ESF workshop therefore proposed that there is a need to develop an experimental simulation of exoplanet atmospheres that may be directly compared with the models.

We therefore plan a small follow up meeting of leading European modellers and laboratory researchers to determine the parameters for a joint modelling/experiment on a simulated exoplanet atmosphere to explore the probability of detecting biosignatures under a variety of physical and chemical conditions. In effect we will create the first simulation of an exoplanet supporting an alien life habitat, we propose to entitle this experiment ‘EITR‘ named after the mythical liquid in Norse mythology that is the origin of all living things.

We anticipate 9-10 participants attending a meeting (drawn primarily from those at the ESF workshop) on the following schedule
Day 1 Arrive Evening Joint session summary of ESF workshop and general discussion
Day 2 Joint Session Introductory talks – The Earth’s early atmosphere - looking for life before photosynthesis and How much life do you need to measure it ?
Breakout sessions to define (i) models and (ii) laboratory experiments
Day 3 Joint Session Defining EITR world for joint lab/modelling project. Departure

Since we fully expect this project to be developed by several different groups future funding for supporting collaborations between these groups is necessary. We expect such funding to be, in part, supported through the recently awarded COST Action CM0805 The Chemical Cosmos within which working group WG3 is dedicated to study of planetary atmospheres (including exoplanet atmospheres) and through the EU Framework VII Research Infrastructure ‘Europlanet’ which provides access to a suite of laboratory facilities simulating planetary conditions. Accordingly we plan this meeting to be arranged with a meeting of the WG3 group of COST Action CM0805 which is to be held at the Open University in the UK January 16-18, 2010

We also plan to produce a briefing document for the wider exoplanet community summarising the conclusions of the ESF workshop and discussing the EITR project, the report will also be put on a website.

Final PROGRAMME

Monday 22 June 2009

Afternoon *Arrival*

18.00-18.30 *Get-together, informal dinner: Meeting point Hotel De La Bourse)*

Tuesday 23 June 2009

09.00-09.20 **Welcome by Convenor**
Nigel Mason (The Open University, Milton Keynes, UK)

09.20-09.40 **Presentation of the European Science Foundation (ESF)**
Sonja Lojen, ESF Standing Committee for Life, Earth and Environmental Sciences (LESC)

09.40-12.30 **Session I: Exoplanets - Defining the habitable zone**

09.40-10.10 Biomarkers – exploring the parameter space toward the first Habitable Planets**"** **Dr Lisa Kaltenegger** (Harvard-Smithsonian Center for Astrophysics, Cambridge, USA)

10.10-10.40 *Coffee / Tea Break*

10.40-11.10 Modelling the architectures of planetary systems
Professor Ewa Szuszkiewicz (University of Szczecin, Szczecin, Poland)

11.10-11.40 Defining the habitable zone
Dr Jonti Horner (The Open University, Milton Keynes, UK)

11.40-12.10 Constraining models of life's emergence: chemical abundances of stars hosting exoplanets.
Dr. Garik Israelian (Instituto de Astrofisica de Canarias, Tenerife, Spain)

12.10-12.30 **Discussion and summary**

12.30-14.00 *Lunch*

14.00-16.00 **Session II: Biosignatures, the identity of life**

14.00-14.30 Techniques and Technologies for biosignature detection
Professor A Quirrenbach (University of Heidelberg, Germany)

14.30-15.01 Astronomical Detection of Biosignatures: temporal variations?
Professor David Field (Aarhus University, Aarhus,Denmark)

15.00-15.30 Mineral products of impact and volcanic crater lakes as planetary biosignatures of life
Professor Jozef Kazmierczak (Institute of Paleobiology, Warsaw, Poland)

15.30-16.00 Carbanaceous meteorites and false atmospheric biosignatuires
Dr Richard Court (Imperial College London, UK)

16.00-16.30 *Coffee / tea break*

16.30-17.00	Solar and extrasolar debris disks **Dr Amaya Moro-Martin** (Centre of Astrobiology, Madrid, Spain)
17.00-18.00	**Discussion**
19.00	Free evening

Wednesday 24 June 2009

09.00-12.30	**Session III: Exoplanetary Atmospheres**
09.00-09.30	Biomarkers in atmospheres of extrasolar super-Earths **Professor Heike Rauer** (DLR, Germany)
09.30-10.00	Can atmospheric spectroscopy provide evidence of life on exoplanets ? **Professor Nigel Mason** (The Open University, Milton Keynes, UK)
10.00-10.30	*Coffee / Tea Break*
10.30-11.00	Extremophile life in exoplanets and their satellites as you can imagine it **Professor Eduardo Janot Pacheco** (Instituto de Astronomia, Universidade de São Paulo, Brazil)
11.00-11.30	3D atmospheric modelling **Ms Mareike Godolt** (Technische Universität Berlin, Germany)
11.30 to 12.30	**Discussion and summary**
12.30-14.00	*Lunch*
14.00-18.00	**Session IV: Looking for vegetation**
14.00-14.30	Observations and modelling of real and plausible (exo)planets **Dr Tommi Koshkinen** (University College London, UK)
14.30-15.00	Spectra of photosynthetic pigments **Professor Kirsti Lehto** (Turku University, Finland)
15.00-15.30	The Earth as an unresolved extrasolar planet : the detection of its vegetation during different climates **Professor Luc Arnold (**Observatoire de Haute Provence, France)
15.30-16.00	*Coffee / tea break*
16.00-16.30	Chirality as biosignature **Professor Harry Lehto** (Turku University, Finland)
16.30-17.30	**Discussion**
19.00	*Conference Dinner*

Thursday 25 June 2009

09.00-10.00	**Session V: Instrumentation**
09.00-09.30	Looking for Astrobiological Signatures with Penetrators on Europa **Dr Rob Gowen** (MSSL, University College London, UK)
09.30-10.00	A chamber for studying planetary environments and its applications to astrobiology **Dr. Eva Mateo Martí** (Centre of Astrobiology, Madrid, Spain)
10.00-10.30	**Guidelines for breakout sessions**
10.30-11.00	*Coffee / Tea Break*
11.00-12.30	**Break out sessions**
12.30-14.00	*Lunch*
14.00-15.00	**Discussion and review of the workshop**
15.00	*Coffee / tea break*
	End of Workshop and departure

Final list of participants

Professor Luc Arnold, Observatoire de Haute Provence, France
Dr Richard Court, Imperial College London, UK
Professor David Field, Aarhus University, Denmark
Ms Mareike Godolt, Technical University Berlin, Germany
Dr Rob Gowan, University College London, UK
Dr Jonti Horner, The Open University, UK
Dr Garik Israelin, Instituto de Astrofiscia de Canarias, Teneride, Spain
Professor Eduardo Janot Pacheco, Universidade de Sao Paulo, Brazil
Dr Lisa Kaltenegger Harvard Smithsonian Centre for Astrophysics, Cambridge, USA
Professor Jozef Kazmierczak, Institute of Paleobiology,Warsaw, Poland
Dr Tommi Koskinen, University College London, UK
Dr Jacek Kreolowski, Torun Centre for Astronomy, Poland
Professor Kirsti Lehto, Turku University, Finland
Professor Harry Lehto, Turku University, Finland
Dr. Sonja Lojen, University of Ljubljana,,Slovenia
Professor Nigel Mason, The Open University, UK
Dr Eva Mateo-Marti, Centre of Astrobiology, Madrid, Spain
Dr Amaya Moro-Martin, Centre of Astrobiology, Madrid, Spain
Professor Antoine Queirrenbach, University of Heidelberg, Germany
Professor Heike Rauer, Technical University Berlin, Germany
Professor Ewa Szuszkiewwicz, University of Szczecin, Poland

Statistical information on participants (age bracket, countries of origin, etc.)

Countries of Origin;	
Brazil	**1**
Denmark	**1**
Finland	**2**
France	**1**
Germany	**3**
Poland	**3**
Slovenia	**1 (Rapporteur)**
Spain	**3**
United Kingdom	**5**
USA/Austria	**1**

Of these 8 were female and 8 Younger Researchers (<30)